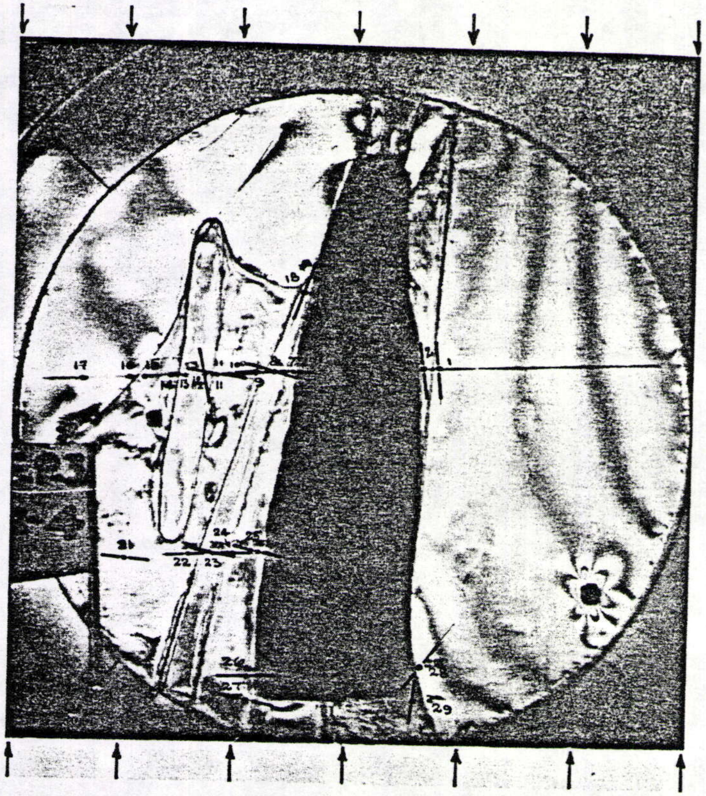

Fig. 6—View of the model after removal of the drifts, undercut slot, and stope; model orientation vertical (+ 90°), showing the directions of measured major principal strains through the points examined at 400 psi vertical, 0 psi horizontal load.

From a study of the reactions in the model, a better understanding is obtained of the correlation between the extensometer readings, and the development of cracks observed in headings adjacent to the mining areas.

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Chapter 29

CLOSURE MEASUREMENTS, AN IMPORTANT TOOL IN MINE DESIGN AT THE CANE CREEK POTASH MINE

by E. A. Wieselmann

This chapter presents a successful approach for achieving mine entry stability at the Cane Creek potash mine by the utilization of closure measurements. The mine is located in southeastern Utah (Fig. 1). Mining is being conducted at depths in excess of 3000 ft under structurally complex geologic conditions typical of the Paradox salt basin.

The closure measurement systems described have definite application for determining relative entry stability in other nonelastic rocks which are similar in behavior to potash. Similar types of closure measurements have been taken in various underground openings throughout the United States, Canada, and Europe. Application of this closure data has previously met with varying degrees of success as a tool for design of underground openings in both elastic and nonelastic media.[1–32]

Closure measurements can be made easily and economically and they provide a practical solution to a practical problem. They are in-situ measurements which do not necessarily require laboratory correlation.

Simple closure measurements have special significance in potash because ''steady-state''* closure rate, or creep, of the entries is measured. These closure rates can be utilized because nonelastic media such as potash will never achieve absolute stability around a mine entry. The potash will tend to creep or deform until all entries are closed and the overburden stress is redistributed over what was previously the mine area. The time for this ultimate effect to occur is dependent on a number of mining and geologic variables. Percentage of mine extraction, mining

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* ''Steady-state'' closure rate of a mine opening is defined as a constant rate of closure. The closure rate does not usually become constant until several months after mining of the entry.

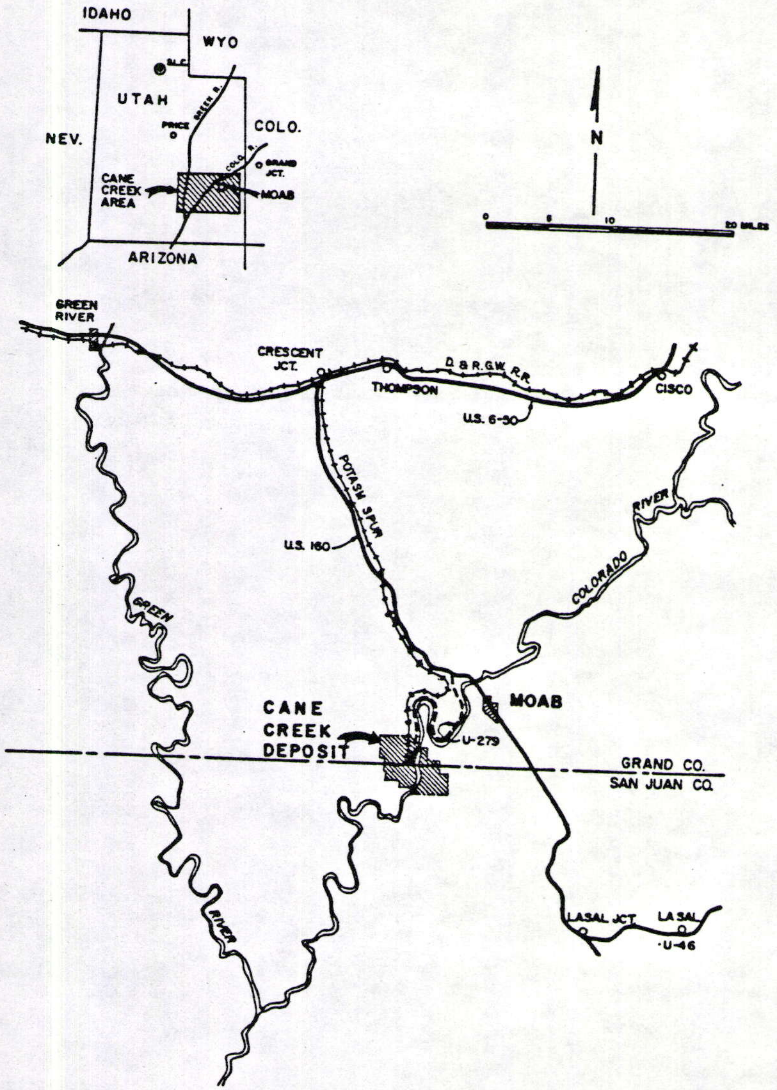

Fig. 1—Location map of Cane Creek potash mine area.

method, depth of overburden, and the stratigraphic sequence above the potash are significant factors affecting complete subsidence over the mine.

The time for a specified percent of the total closure of a mine opening to occur must be accurately determined in deep potash mining. Closure beyond this amount would render the haulage entries useless and the ventilation entries ineffective. The usable life of a particular entry will affect mine planning with respect to layout of development entries and production panels. At the Cane Creek potash mine other factors than those listed affect mine subsidence and opening closure rates. The geometry of mine entries and the distance to shale overlying the ore bed have been found to be extremely important.

The ability to accurately predict the usable life of entries under specific combinations of mining and geologic variables is of great importance. Once this ability is acquired for a particular mine, closure rates become an invaluable tool in design of mine openings.

MEASUREMENT SYSTEM

Convergence measurements usually are taken between two opposite points on the surface of the mine opening. Another method is to measure the relative movement of points at various distances in the rock beyond the surface of the mine opening. These relative rock movements are measured along a line normal to the surface of the entry. These two types of measurements may be made separately or they can be combined at a single location.

A vertical convergence station measures closure between reference points on the roof and floor, at the centerline of the entry. A horizontal convergence station measures closure between opposite ribs at the mid-height of the entry. A combined vertical and horizontal convergence station is shown schematically in Fig. 2.

Rock bolt extensometers are used to measure relative movement in the roof and ribs. These extensometers consist of a free-floating rock bolt anchored only in the bottom of the drill hole. The bolt is free to move along the axis of the borehole. Any axial movement of the bolt is referenced to the collar of the hole. Several of these rock bolt extensometers are installed in clusters and at various depths at a single location (Fig. 3). Usually three rock bolt extensometers are placed at depths of 6, 12, and 18 ft in the roof along the centerline of an entry. Four rock bolt extensometers are usually installed in opposite ribs along the mid-height at depths of 2, 4, 6, and 8 ft.

Vertical convergence profiles across the entry and pillar shortening

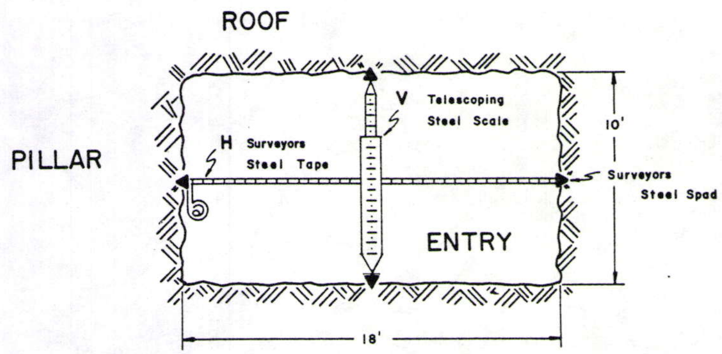

Fig. 2—Combined vertical and horizontal convergence station. V *is vertical measurement;* $\Delta V/\Delta T =$ *vertical closure rate;* H *is horizontal measurement;* $\Delta H/\Delta T =$ *horizontal closure rate, where* ΔT *is specified time interval during steady-state creep.*

measurements are usually made in association with the rock bolt extensometer measurements (Fig. 4).

The instrumentation necessary to accurately measure mine entry closure is simple, inexpensive, reliable, and reproducible under identical conditions in the mine.

A telescoping steel rod and a tensioned steel surveyor's tape, both reading to $\frac{1}{16}$ in., are used for making routine vertical and horizontal

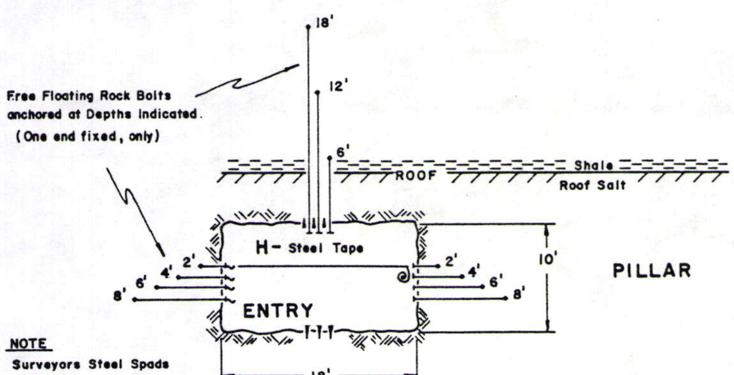

Fig. 3—Rock bolt extensometers in mine roof and pillars. H *is horizontal measurement between ends of "free-floating" rock bolts anchored at same depth.* $\frac{1}{2}(\Delta H)/(\Delta T) \approx$ *axial closure rate in pillar at depth measured, where* ΔT *is specified time interval during steady-state creep. See Fig. 7 for details of roof measurements.*

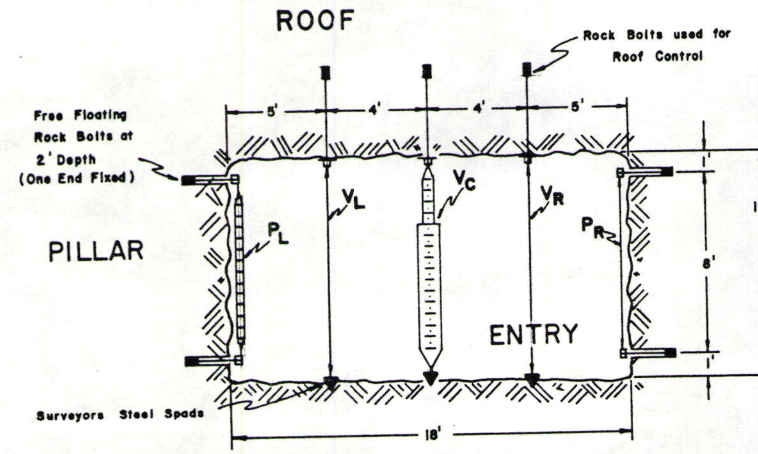

Fig. 4—Vertical convergence profile and pillar shortening measurements. V_L, V_C, V_R, P_L, *and* P_R *are vertical measurements made with telescoping steel scale.* $\Delta V_C/\Delta T$ *is vertical closure rate (center of entry),* $\Delta P_L/\Delta T$ *is pillar shortening rate (left pillar).* ΔT *is specified time interval during steady-state creep.*

convergence measurements, respectively. The photograph in Fig. 5 shows both vertical and horizontal closure measurements being taken in a typical 8-ft high by 14-ft wide ovaloidal borer entry in the Cane Creek potash mine.

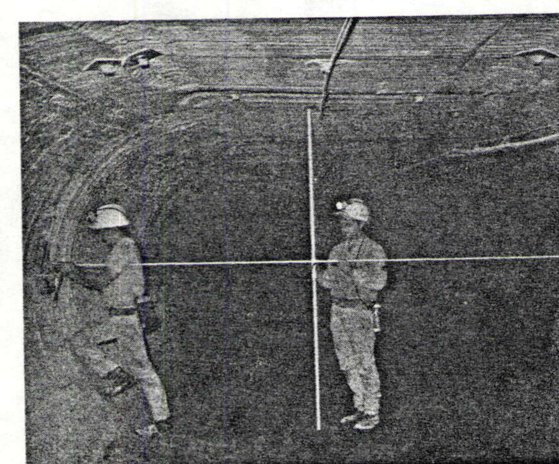

Fig. 5—Making closure measurements in ovaloidal borer entry.

Where greater sensitivity or greater precision is required, vertical rods with dial gages and weighted horizontal tapes with verniers, both reading to 1/1000-in., are used. A typical use for convergence instruments with higher sensitivity would be to speed up the determination of a very low "steady-state" closure rate, or creep, of a particular inactive potash mine entry. A recent application for precision instrumentation was in monitoring closure rates during enlargement of the ore bins, which had been excavated four years earlier. Fig. 6 is a photograph of precision vertical and horizontal closure measurements being taken in a 20×20-ft sq entry above the ore bins. The entry was originally mined and enlarged by drilling and blasting. The vertical closure measurement is made to 1/1000-in. between a reference point on the floor and one on a weighted hanging wire.

Single-position borehole extensometers, or simple rock bolt extensometers, are used for determining strain gradients in the potash beyond the surface of a mine opening at Cane Creek. Again, depending on the desired sensitivity, these instruments can be read at increments of $\frac{1}{16}$, $\frac{1}{64}$, or 1/1000-in. as desired. Relative amounts of roof sag and floor heave are most easily determined by this rock-bolt extensometer. The schematic diagram in Fig. 7 shows how these rock bolt extensometers are installed and read.

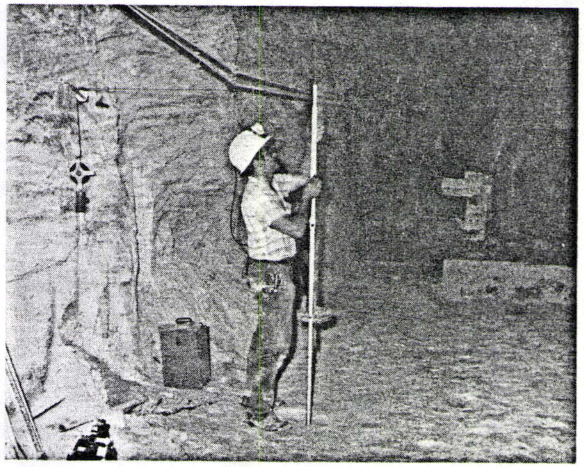

Fig. 6—Making closure measurements in square, conventionally mined entry.

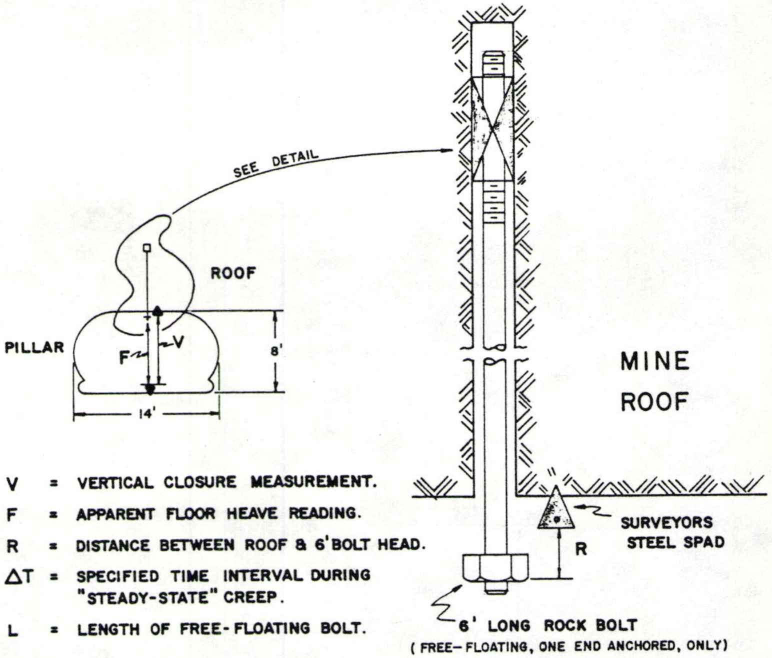

Fig. 7—Roof sagmeter installation and measurement. $\Delta V/\Delta T$ is vertical closure rate of entry; $\Delta F/\Delta T$ is apparent floor heave rate with respect to point 6 ft above roof; $\Delta R/\Delta T = (\Delta V/\Delta T - \Delta F/\Delta T) = (\Delta V - \Delta F)/\Delta T$ is sag rate in 6-ft roof beam; and $(\Delta R/\Delta T)/(1/L - R_o) \approx$ average strain rate from 0 ft to anchor at 6 ft in roof. R_o is initial distance between roof and 6-ft bolt head.

APPLICATION AT CANE CREEK

The first step in establishing a closure measurement system at the Ca
Creek mine was to place vertical convergence measurement stations
every intersection in the active mine areas.

This work began in January 1966. At that time, mining was being c
ducted on an irregular geometric pattern (see northeastern portion
the mine map in Fig. 8). This irregular mining pattern had been nec
sitated by the very steep local folding which had been encountered alm
from the time at which mining first began in the ore body.

The initial closure measurements revealed that a regular geome
mining pattern should be maintained in spite of the geologic structu
not only for reliable prediction of closure rates, but also for long-te
entry stability. Even with the irregular geometry, it was noted i

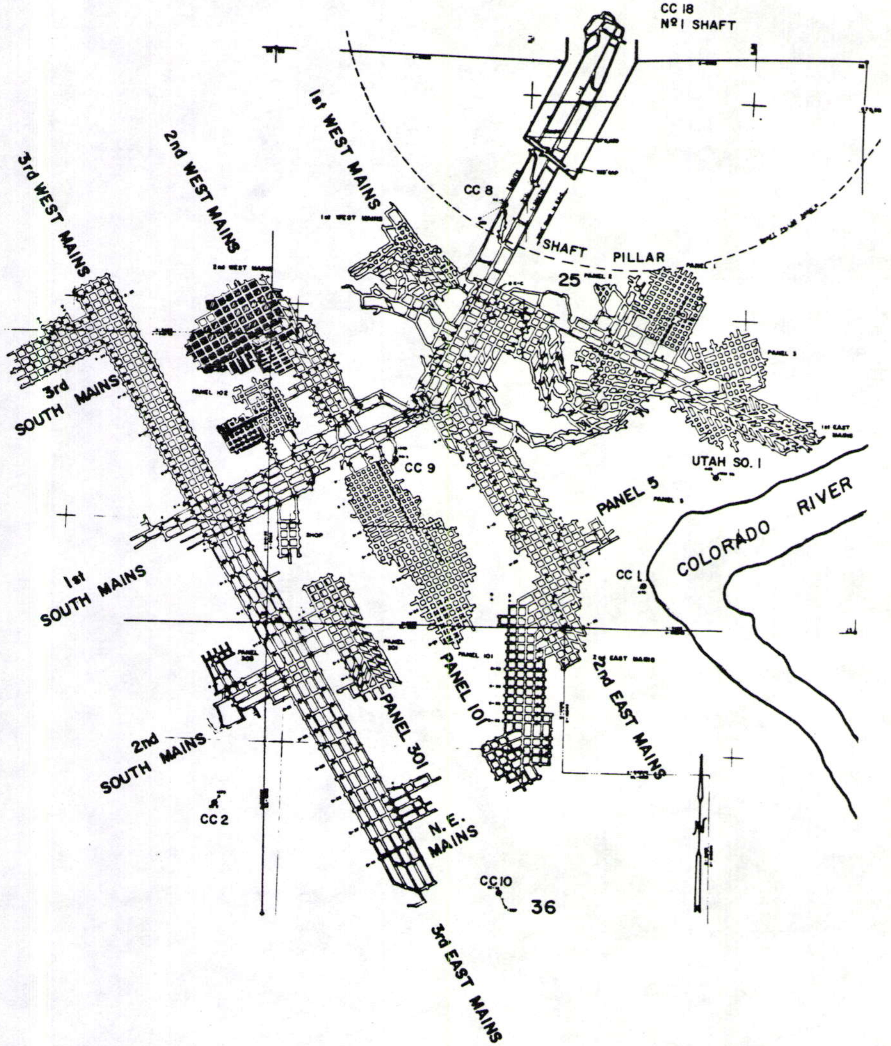

Fig. 8—Location map, Cane Creek mine.

qualitative way that the vertical closure rate was related to certain geologic and mining variables. These variables were distance to overlying shale, entry width, and percentage extraction. The initial data also supported the concept of a protected main entry system with barrier pillars separating the entry system from production panels. This mining system has been implemented, as shown in the southwestern portion of the mine map in Fig. 8.

A detailed mapping program was undertaken simultaneously with the initial installation of the vertical convergence stations. This program involved mapping and classifying the visually observed deformations in every entry of the mine. The visual deformations observed in the roof, ribs, and floor were generally classified as to the degree of flowage, bending, and fracturing. A simplified classification of the actual system used for the visually observed roof deformations at Cane Creek is given in Table 1.

Gradational changes in the deformation from the new headings to the older entries indicated that a definite deformational sequence, changing with time, existed for the Cane Creek potash ore bed. This detailed deformation mapping was updated periodically for the entire mine. Finally, the change in visual deformation was correlated with vertical convergence curves from the time of mining. This correlation of visual

Table 1. Simplified Classification of System Used for Visually Observed Roof Deformations at Cane Creek

Degree of Deformation	Visual Observations		
	Roof	Rib	Floor
Minor	No shear or tension cracks	Small vertical shear cracks with spalling	No visible deformation
	Slight downward roof sag	No rib bowing	
Major	Shear cracks at roof-rib line	Vertical shear and extension cracks	Visible tension cracks in floor
	Detached roof slabs with secondary tension cracks	Rib sloughing	Visible floor heave
	Noticeable roof bowing	Slight rib bowing	

deformation and closure measurements has been quite useful in understanding both the deformational behavior and the physical nature of the ore deposit.

Once a specified mining pattern with symmetrical geometry was established for main entries and panels, a system of combined types of closure measurements was established in these new mine areas. These closure measurements allowed steady-state closure rate predictions and determinations to be made for various entry systems with respect to certain mining and geological variables.

The important geometric variables which can be controlled in an entry system are the number, center spacing, width, and width to height ratios of entries. Pillar sizes, percentage extraction, rate of advance, and time of rock bolting are also key mining variables which have shown a relationship to mine closure rates. Important geological variables at Cane Creek are distance to overlying shale, lithology in and above the ore bed, attitude of local and regional folding in the ore bed, and depth of overburden.

RESULTS

The most significant result obtained from the simple closure measurement system is the ability to predict and control the steady-state closure rates of mine entries.

During the past two years, closure rates have been reduced 50% in main entries and 75% in advancing room-and-pillar production panels. The main entries are being mined by boring machines, continuous ripper miners, and by drilling and blasting at extractions ranging between 29% and 44%. All production panels are being mined by drilling and blasting at extractions ranging between 49% and 70%.

This great reduction in entry closure rates has been achieved by changing to a mine entry design based upon the interaction between four specific mining and geological variables. These variables are entry width and height, pillar size, percentage extraction, and distance to overlying shale.

Two general closure rules have been established for the potash deposit. These following rules have varied only slightly since the earliest measurements were taken in mine areas with regular geometric patterns.

1) At the surface of the mine openings, horizontal closure ranges between 60% and 100% of the vertical closure; the average horizontal closure is nearly 100% of the vertical closure. Fig. 9 shows the horizontal and vertical closure relationships for a conventionally mined rectangular entry 10 ft high by 18 ft wide.

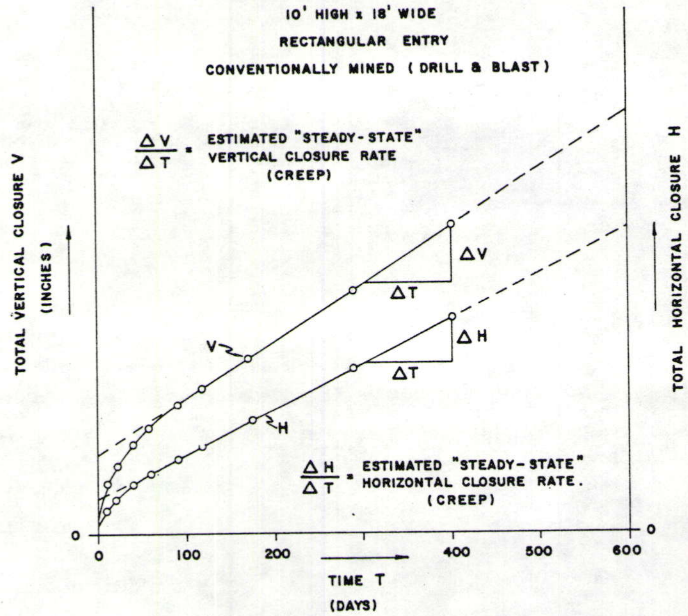

Fig. 9—Typical vertical and horizontal closure curves.

2) Floor heave ranges between 60% and 90% of the total vertical closure; the average floor heave accounts for approximately 70% of the vertical closure. Fig. 10 shows typical closure curves for the floor heave and roof sag components of the vertical closure of a rectangular entry 10 ft high by 18 ft wide that has been conventionally mined by drilling and blasting. See also Fig. 7.

The closure rates at the surface of the openings are not expressed as strain rates but as actual closure rates for a particular location. The basic reason for reporting actual closure rates at the Cane Creek potash mine is to aid communications with the operating personnel.

Reduction of these entry closure rates to strain rates between opposite points on the surface of the openings has not provided additional useful information. However, reduction of data from clusters of rock bolt extensometers placed in roof or pillars to strain rates has been valuable in analyzing the behavior of the potash beyond the surface of the entries. Fig. 11 shows the zones of potential roof separation as those with a very high strain rate. Also, this figure shows normal strain gradients in the pillars surrounding a 10-ft high by 18-ft wide rectangular entry mined by drilling and blasting.

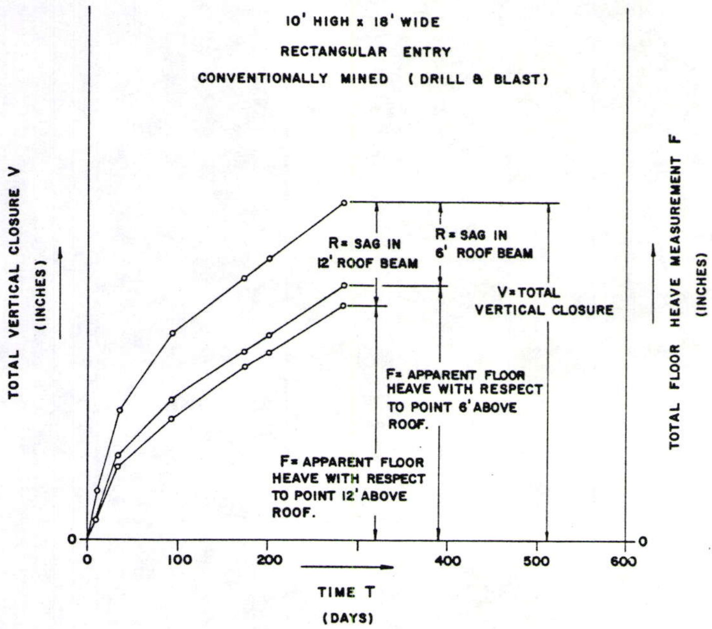

Fig. 10—Typical roof sagmeter curves. See also Fig. 7.

A number of qualitative relationships between closure rates and geologic and mining variables are known to exist in the Cane Creek potash mine, as follows:

1) Floor heave is predominant along the crests of local anticlines in the ore body. Roof sag is more likely to occur along the troughs of adjacent local synclines.

2) Roof separation occurs along the interface between the near roof salt and the overlaying shale. The changes in strain rate, as indicated by the rock bolt extensometers, illustrate this phenomenon (Fig. 11). This figure also gives an indication of the adequacy of rock bolting.

3) Vertical closure rates increase as the distance to the overlying shale is decreased (Fig. 12).

4) Vertical closure rates increase with either increase in entry width or increase in percentage extraction (Figs. 13 and 14). Data have been available for entry widths ranging from 14 to 28 ft and for mine extractions ranging between 20% and 94%.

5) The ovaloidal cross section of the boring machine yields the lowest rate of entry closure. Rectangular entries made by the ripper miner

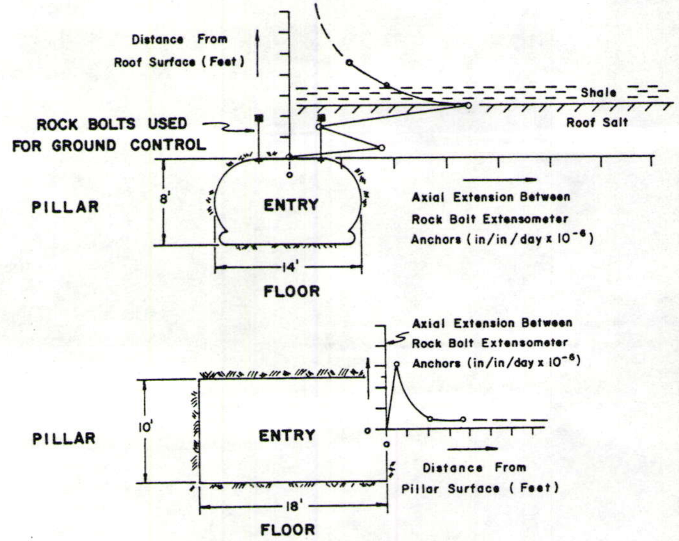

Fig. 11—Strain rate gradients in the mine roof and pillars. See Fig. 3 for arrangement of instruments used to obtain data for curves.

show an intermediate closure rate. Rectangular entries mined by drilling and blasting techniques show the greatest rate of closure (see Fig. 15).

6) No single orientation of entries appears to give lower entry closure rates in the ore body.

Statistical studies of the rock mechanics data are being continued. Multiple linear and curvilinear regression analyses appear to be useful in statistical treatment of the closure data with respect to the mining and geologic variables. These investigations will result in quantitative statistical relationships between steady-state closure rates and those particular mining and geologic variables which are found to significantly affect entry stability.

These studies ultimately will develop prediction equations for determining the steady-state closure for specified mine entry systems when certain mining and geologic variables are controlled. The reliability of such equations can be determined in order to give a certain degree of confidence in predicted closure rates over the life of the potash mine.

The entire rock mechanics program to date at the Cane Creek mine indicates that the distance to overlying shale and percentage of extraction are two of the most significant variables affecting the closure rate.

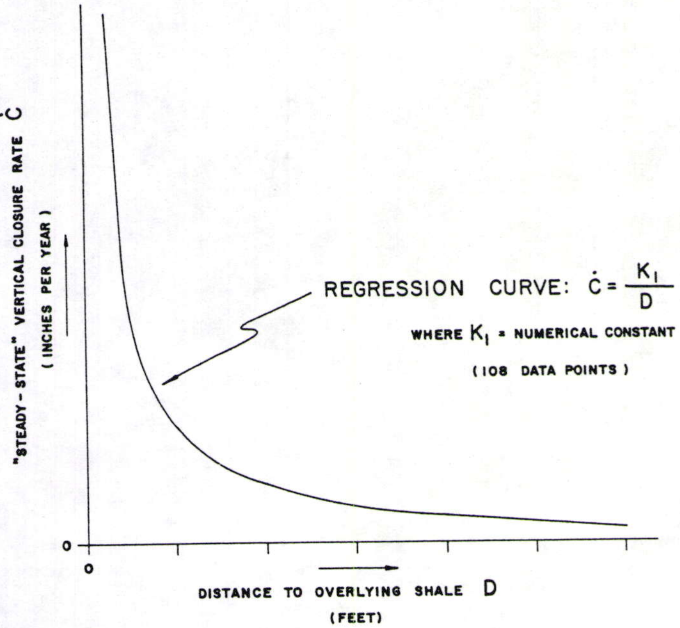

Fig. 12—Vertical closure rate vs. distance to overlying shale.

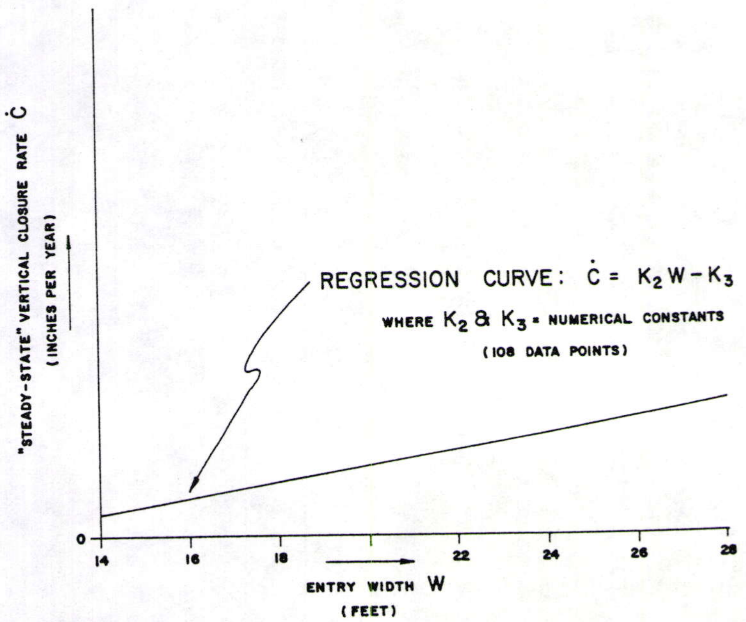

Fig. 13—Vertical closure rate vs. entry width.

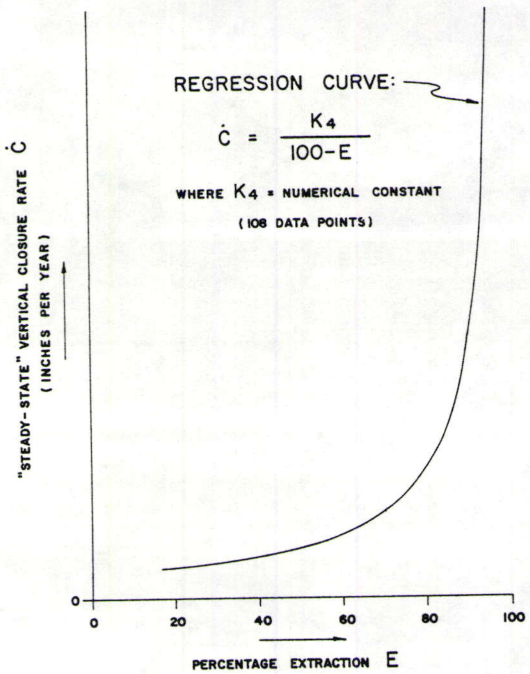

Fig. 14—Vertical closure rate vs. percentage extraction.

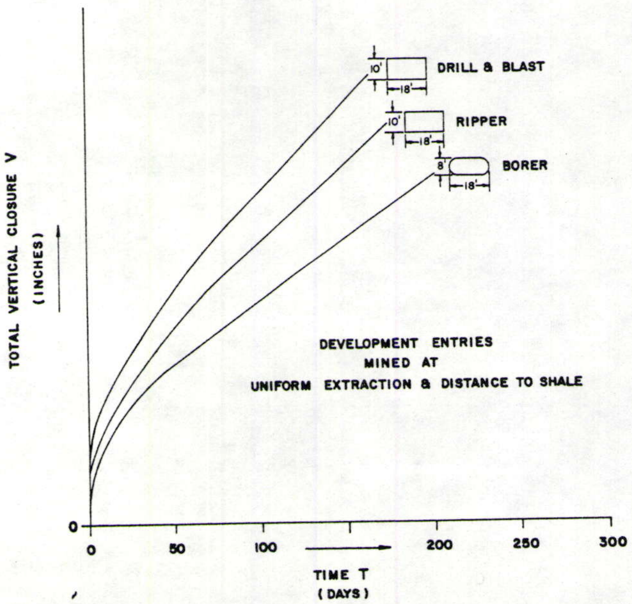

Fig. 15—Comparison of vertical closure curves for typical borer, ripper, and conventional mine entries.

CONCLUSIONS

This system of closure measurements has been useful in guiding the design of mining openings in the geologically complex potash deposit at the Cane Creek mine. The nonelastic nature of the potash bed, coupled with overburden depths in excess of 3000 ft, required that entry closure rates be controlled. The establishment of controls to maintain a minimum entry closure rate is possible through a planned system of simple closure measurements. It is through these closure measurements that creep rates can be predicted and related to the effects of mining and geologic variables.

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Chapter 30

INFLUENCE OF GEOLOGICAL STRUCTURE ON FAILURE AROUND CERTAIN TYPES OF UNDERGROUND EXCAVATIONS

by R. Lyndon Arscott and P. Hackett

This chapter reviews the early stages of a study designed to investigate the physical behavior of the coal measure rocks around longwall panels over a relatively large area. The aim of the work is to attempt to explain a directional tendency for a certain type of underground fracture. The geological structure of the area is reasonably uniform but the effect of some local anomalies is also discussed. Although some definite tendencies have been recorded, the results so far achieved need confirmation by further experiments. The chapter deals first with some in-situ strain measurements carried out in longwall panels and continues with a discussion of the relationships between induced fractures and the natural variations in the structure of the rock mass. Finally, some light is shed upon the gas outburst phenomenon although eradication of the hazard is far from assured.

STRESS AROUND A LONGWALL PANEL

Considerable progress has been made during the last few years towards the determination of the mechanism of failure of small samples of rock under varying environmental conditions. Much more laboratory testing needs to be done in this field but an even greater amount of study needs to be devoted to the extrapolation of laboratory phenomena to failure around underground excavations. The problem is made more difficult because the stress redistribution around an excavation is often difficult to define, particularly when part of the rock mass fails and a

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